Design of Equitable Dominating Set Based Semantic Overlay Networks with Optimal Fast Replica Algorithm for Resilient and Balanced Content Distribution

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***Abstract*— Content Distribution Networks (CDNs) are overlay networks for placing the content near the end clients with the aim at reducing the delay, network congestion and balancing the workload, hence improving the service quality perceived by the end clients. The main objective of this work is to construct a semantic overlay network of surrogate servers based on equitable dominating set. This yields any replication algorithm that can replicate the contents to minimum number of surrogate servers within the SON. Such servers can be accessed from anywhere. Then we propose a content distribution algorithm named Optimal Fast Replica (O-FR) and apply our proposed algorithm to distribute the content over the Equitable Dominating set based Semantic Overlay Networks (EDSON). We analyze the performance of our proposed Optimal Fast Replica (O-FR) in terms of average replication time, and maximum replication time and compare its performance with existing content distribution algorithms named Fast Replica and Resilient Fast Replica. The result of such approach improves the service quality perceived by the end clients. This paper also analyzes the use of equitable dominating set for the construction of semantic overlay networks and also investigates how it is useful for maintaining the uniform utilization of the surrogate servers.**

***Index Terms*— SON, Dominating set, CDN, DSON, Optimal Fast Replica.**

I. INTRODUCTION

Content Delivery Networks (CDNs) have evolved to overcome the limitations of the Internet in terms of user perceived Quality of Service (QoS) when accessing web content. A CDN replicates content from the origin server to surrogate servers, scattered over the globe, in order to deliver content to end users in a reliable and timely manner from a nearby optimal surrogates.

Apart from the pure networking issues of the CDNs relevant to the establishment of the infrastructure, some more issues such as selection of surrogate server for replication and retrieval, content replication policy, and caching.In this paper, we analyze the role of selection of surrogate server for optimum replication of content in the CDN, application of different content replication policies and their working mechanisms.

This paper is organized as follows. The next section describes about the related work. Then, we present our design of equitable dominating set based semantic overlay network and optimal fast replica content distribution algorithm in Section III and a discussion on the analytical study, experimental results and analyze the performance of different content distribution algorithms in Section IV. Finally, the conclusion and future work is presented in Section V.

II. RELATED WORK

Content Delivery Networks provide services that improve network performance by maximizing bandwidth, improving accessibility, and maintaining correctness through content replication. They offer fast and reliable applications and services by distributing content to surrogate servers located close to users.

In order to offload popular servers and improve end-user experience, copies of popular content are often stored in different locations. With mirror site replication, files from origin server are proactively replicated at surrogate servers with the objective to improve the user perceived Quality of Service (QoS). When a copy of the same file is replicated at multiple surrogate servers, choosing the server that provides the best response time is not trivial and the resulting performance can dramatically vary depending on the server selected [1].

Laurent Massoulie [2] proposed an algorithm called the localizer which reduces network load, which helps to evenly balance the number of neighbors of each node in overlay, sharing the load and improving the resilience to random node failures or disconnections.

Rodriguez [3] and Biersack proposed a dynamic parallel-access scheme to access multiple mirror servers. In their study, a client downloads files from mirror servers residing in a wide area network. They showed that their dynamic parallel downloading scheme achieves significant downloading speedup with respect to a single server scheme. However, they studied only the scenario where *one* client uses parallel downloading. They failed to address the effect and consequences when all clients choose to adopt the same schemeColor figures will be L. Cherksova [4], and J. Kee proposed Fast Replica algorithm to distribute the content, in which a user downloads different parts of the same file from different servers in

DOI: 01.IJNS.01.03.24

parallel. Once all the parts of the file are received, the user reconstructs the original file by reassembling the different parts.

Al-Mukaddim Khan Pathan and Rajkumar Buyya [5] presented a comprehensive taxonomy with a broad coverage of CDNs in terms of organizational structure, content distribution mechanisms, request redirection techniques, and performance measurement methodologies. They studied the existing CDNs in terms of their infrastructure, request-routing mechanisms, content replication techniques, load balancing, and cache management.Dominating sets have been used successfully in topology control in wireless Ad hoc networks [6, 7] and virtual back creation in sensor networks [8].

ZhiHui Lu [9] et al proposed a novel content push policy, called TRRR i.e. Tree-Round-Robin-Replica which yields an efficient and reliable solution for distributing large files in the content delivery networks environment. They carried out some experiments to verify TRRR algorithm in small scale. They also demonstrated in experiment that TRRR significantly reduces the file distribution/replication time as compared with traditional policies such as sequential unicast and multiple unicast.

Amutharaj. J and Radhakrishnan. S [10, 11] constructed a dominating set based overlay network to optimize the number of servers for replication. They investigated the use of Fast Replica algorithm to reduce the content transfer time for replicating the content within the semantic overlay network and compared its performance with sequential unicast, multiple unicast content distribution strategies in terms of content replication time and delivery ratio.

Srinivas Shakkottai and, Ramesh Johari [12] evaluated the benefits of a hybrid system that combines peer-to-peer and a centralized client–server approach against each method acting alone. They investigated the relative performance of peer-to-peer and centralized client–server schemes, as well as a hybrid of the two—both from the point of view of consumers as well as the content distributor.

Ye Xia [13] et al considered a two-tier content distribution system for distributing massive content and proposed popularity-based file replication techniques within the CDN using multiple hash functions. They developed a set of distributed, robust algorithms and evaluated the performance of proposed algorithms.

Oznur Ozkasap [14], Mine Caglar and Ali Alagoz proposed and designed a peer-to- peer system; SeCond, addressing the distribution of large sized content to a large number of end systems in an efficient manner. It employed a self-organizing epidemic dissemination scheme for state propagation of available blocks and initiation of block transmissions. They showed that SeCond is a scalable and adaptive protocol which took the heterogeneity of the peers into account.

III. DESIGN OF EQUITABLE DOMINATING SET BASED SON WITH OPTIMAL FAST REPLICA FOR CONTENT DISTRIBUTION

A. EDSON Based Surrogate Server Selection

Semantic Overlay Network ‘G’ can be defined as follows.

$$G = \{V, E\} \qquad \text{------------------ (1)}$$

Where $V = \{V_1, V_2, V_3, .. V_n\}$ be the set of surrogate servers and E is the set of edges between i^{th} surrogate server and j^{th} surrogate server i.e. $E= (V_i, V_j)$ such that $V_i \neq V_j$.

Let D be the dominating set of G and $D \subset G$, the server not in D is adjacent to at least one surrogate server in D. Hence, all the surrogate servers are either member of D or V\D.

Equitable Dominating set D is a set of ‘r’ dominating vertices in V since $|D|$ = r and V\D is the set of all the adjacent vertices of dominating server set D such that the difference between the degrees of all the vertices in D can differ utmost by 1. Each vertex v in D has more or less same number of neighbor nodes which are members of V\D. So contents are only replicated in the set of surrogate servers D which contains ‘r’ surrogate servers or less than ‘r’ number of surrogate server’s i.e. $|D| \leq |V|$.

B. Algorithm for Formation of Equitable Dominating Set based SON (EDSON):

Step 1:The algorithm begins by marking all the vertices of the graph white.

Step 2:Algorithm selects the vertex with the maximal number of white neighbors.

Step 3:The selected vertex is marked black and its neighbors are marked gray.

Step 4:The algorithm then iteratively scans the gray nodes and their white neighbors, and selects the gray node or the pair of nodes (a gray node and one of its white neighbors), whichever has the maximal number of white neighbors.

Step 5:The selected node or the selected pair of nodes is marked black, with their white neighbors marked gray.

Step 6:Once all the vertices are marked gray or black, the algorithm terminates. All the black nodes form a connected dominating set (CDS).

Step 7: After forming the CDS, check the degree of each vertices of the connected dominating set.

Step 8: If the degree of any vertex vary more than one then mark that vertex gray and find the suitable alternate vertex as the member of the dominating set and mark it black. If no alternate node is found then leave as it is.

C. Working Principles of Optimal Fast Replica in EDSON

In order to offload popular servers and improve end-user experience, copies of popular content are often replicated in multiple surrogate servers which are scattered over geographically different locations based on some content distribution policy. In this paper, content

DOI: 01.IJNS.01.03.24

distribution policies such as sequential unicast, multiple unicast, Fast Replica(FR)[5,16,17,18], Resilient Fast Replica(R-FR)[5,16,17,18], and Optimal Fast Replica(O-FR), are used to distribute the content from origin server to set of surrogate servers in the EDSON.

The objective of Optimal Fast Replica (O-FR) is to minimize the maximum replication time. The working principle of Optimal Fast Replica can be described as follows.

Step 1: Partition the Original file F into 'm' sub files of equal size.

Size (F_i) = Size (F)/ m bytes where 1<=i<=m and m=n/2

Step 2: Surrogate server N_0 opens 'm' concurrent connections to surrogate servers N_1, N_2,….N_m. N_0 will send each node N_i the following file and information.

- Surrogate Server list: R = {N_1, N_2 ... N_m} (In next step, sub-file F_i will be forwarded to this server list.
- Sub-file F_i.
- Replica amount: k (1<= k <= m).

Step 3: Every surrogate server $N_i \in$ {N_1,N_2, …N_m}opens k-1 concurrent connections and replicate the sub file F_i to the group with k-1 surrogate servers defined in the set { N_j, i<j<i+k, if j<m, then j=(j-1)mod m+1}

In this step, every server N_i {N_1,N_2,…,N_m} has the following output links and input links.

- K-1 Output Links : forwarding sub-file Fi to node list { Nj, i<j<i+k, if j<m, then j=(j-1) mod m+1 }
- K-1 Input Links : receiving sub-file F_j from server list { N_j, i-k <j<i, if j<1, then j = j+m }

Step 4 : At last, every node N_i holds k sub files, { F_j, i-k <j <= i, if j<1, then j = j+m }

In general case, node list N_i {N_1, N_2,…, Nm}, as cache servers and supports concurrent download.

Client Content Request Processing:

When a user client requests file F from origin server that request will be redirected to the surrogate server list {N_1, N_2… N_m}, and concurrently downloads every sub-file F_i. Then the sub-files will be reassembled in to original file F in the client machine.

In the ideal case, when k=m, every surrogate server N_i holds all of m sub-files of original file F and reorganizes them to form the Original file F in the local node. When the user requests file F from the origin server, the request will be redirected to one surrogate server in the list {N_1, N_2... Nm} and download the whole file F.

IV. RESULTS AND DISCUSSIONS

A. Analytical Study

Let Time denote the transfer time of file F from the origin server N_0 to surrogate server N_i as measured at N_i. Two performance metrics: average and maximum replication times are considered.

Average Replication Time:

$$Time_{avg} = 1/n * \sum_{i=1}^{i=n} Time_i$$

Maximum Replication Time: $Time_{Max}$ reflects the time when all the surrogate servers in the overlay network receive k-subfiles (1<=k<=m) of the original file.

$Time_{Max}$ = max {Timei} where i =1...n

In idealistic setting all the nodes and links are homogeneous, and let each node can support 'n' network connections to other nodes at B bytes/sec. Then,

$$Time_{distribution} = Size (F) / (nxB) \qquad (2)$$

$$Time_{collection} = Size (F) / (nxB) \qquad (3)$$

B. *Performance of Content Distribution Algorithms in an 'n' server Semantic Overlay Network*

Time taken for distributing the content over the Semantic Overlay Network by different content distribution algorithms are presented in Table I.

TABLE I
CONTENT DISTRIBUTION TIMES OF DIFFERENT CONTENT DISTRIBUTION ALGORITHMS

Algorithm	Content Distribution Time(T_D)
Sequential Unicast	n * Size (F) / B
Multiple Unicast	Size (F) / B
Fast Replica	2 x Size (F) / (nxB)
Resilient Fast Replica without Node Failure	2 x Size (F) / (n x B)
Resilient Fast Replica with Failure of 'm' servers	(2+m/n) * Size (F) / (nxB)
Optimal Fast Replica	((k+n) / n*n*k) * Size (F) / B

Replication Time proportion of different content distribution algorithms is tabulated in Table II.

TABLE II
REPLICATION TIME PROPORTION OF DIFFERENT CONTENT DISTRIBUTION ALGORITHMS

Algorithm	Replication Time Proportion
Sequential Unicast	n
Multiple Unicast	1
Fast Replica	2/n
Resilient Fast Replica without Node Failure	2/n
Resilient Fast Replica with Failure of 'm' servers	(2+m/n)*1/n
Optimal Fast Replica	((k+n) / n*n*k)

C. Performance of Content Distribution Algorithms in Equitable Dominating Set based Semantic Overlay Network

Equitable Dominating set D is a set of 'r' dominating surrogate servers in surrogate server set V and V\D is the set of all the adjacent vertices of dominating node set D such that the difference between degree of all the vertices in D can differ utmost by 1.Each vertex 'v' in V has more or less same number of neighbor nodes which are members of the adjacent servers set V\D. So contents are only replicated in the equitable dominated set of surrogate servers D instead of V. Suppose Cardinality of D is 'r' or a value less than 'r' then the contents will be replicated in utmost 'r' number of surrogate servers which is always less than 'n'. i.e. $|D| \leq |V|$.

Therefore, Replication Time proportion of different content distribution algorithms such as sequential unicast, multiple unicast, Fast Replica (FR), Resilient Fast Replica(R-FR), and Optimal Fast Replica (O-FR) in EDSON can be expressed as follows:

r : 1: 2/r : (2+m/r)*1/r : ((k+r) / r*r*k) where r < n.

D. Simulation Experimental Study and Analysis:

To evaluate the CDN, we used our complete simulation environment, called CDNsim [24], which simulates a main CDN infrastructure. It is based on OMNeT++ library which provides a discrete event simulation environment.

All CDN networking issues, such as surrogate server selection, SON formation, replicating the content from origin server to surrogate servers, implementing the replication algorithms, propagation, and queuing are computed dynamically via CDNsim, which provides a detailed implementation of the TCP/IP protocol, implementing packet switching, packet transmission upon misses etc.

Performance of different content distribution schemes in terms of Average Replication Time:

We experimented with 12 different size files; 100 KB, 750 KB, 1.5 MB, 3 MB, 4.5 MB, 6 MB, 7.5 MB, 9 MB, 36 MB, 54 MB, 72 MB, 128 MB and 8 surrogate servers. Fig. 1 shows the average replication time measured by different individual surrogate servers for different file sizes of 100 KB, 750 KB, 1.5 MB, 3 MB, 4.5 MB, 6 MB, 7.5 MB, 9 MB, 36 MB, 54 MB, 72 MB, 128 MB when 8 surrogate servers are in the replication set. High variability of average replication time under Multiple and Sequential Multicast is identified for larger file sizes.

Average content replication time under Optimal Fast Replica algorithm across different file sizes in an 8 surrogate servers replication set is much more stable and predictable. Hence, Optimal Fast Replica outperforms most of the cases than sequential unicast, multiple unicast, Fast replica, and Resilient Fast Replica(R-FR) content distribution schemes.

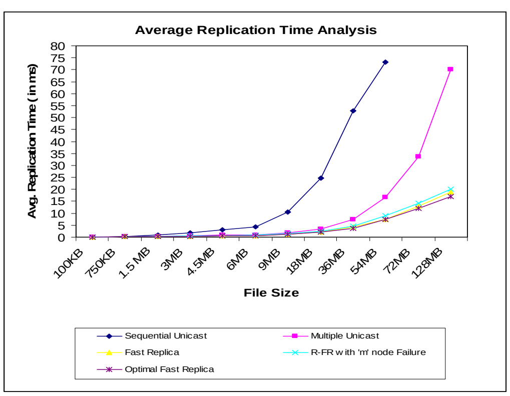

Fig.1.Average Content Replication Times for various schemes

Performance of different content distribution schemes in terms of Maximum Replication Time

We experimented with 12 different size files; 100 KB, 750 KB, 1.5 MB, 3 MB, 4.5 MB, 6 MB, 7.5 MB, 9 MB, 36 MB, 54 MB, 72 MB, 128 MB and 8 surrogate servers.

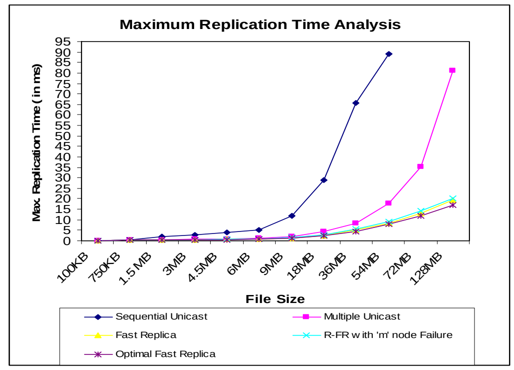

Fig. 2. Maximum Content Replication Times for various schemes

"Fig. 2," shows the maximum replication time measured by different, individual recipient nodes for different file sizes of 100 KB, 750 KB, 1.5 MB, 3 MB, 4.5 MB, 6 MB, 7.5 MB, 9 MB, 36 MB, 54 MB, 72 MB,128 MB when 8 surrogate servers are in the replication set. High variability of maximum replication time under Sequential Unicast and Multiple Unicast is identified. Maximum File replication time under Optimal Fast Replica (O-FR) algorithm across different file sizes in an 8 surrogate servers replication set are much more stable and predictable. Hence, Optimal Fast Replica (O-FR) algorithm outperforms most of the cases than sequential unicast, multiple unicast, Fast replica, and Resilient Fast Replica(R-FR) content distribution schemes.

Analysis on the impact of Equitable Dominating Set based SON

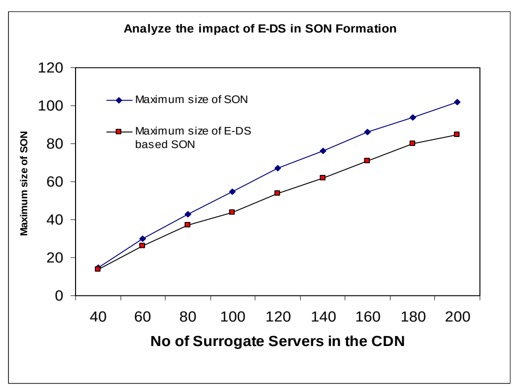

Fig. 3. Impact of Equitable Dominating Set in SON based CDN Formation

By the implementation of equitable dominating set for the clustering of surrogate servers in the SON, the average number of surrogate servers for content replication is reduced to 60 percentages or less. Although the number of surrogate servers is reduced, there will not be any change in the redundancy because of the proposed Optimal Fast

DOI: 01.IJNS.01.03.24

Replica(O-FR) content distribution algorithm used for distributing the content to different surrogate servers and collect the content from the replica servers and reconstruct them locally.

Performance of different content distribution schemes in Equitable Dominating Set based SON in terms of Average Replication Time:

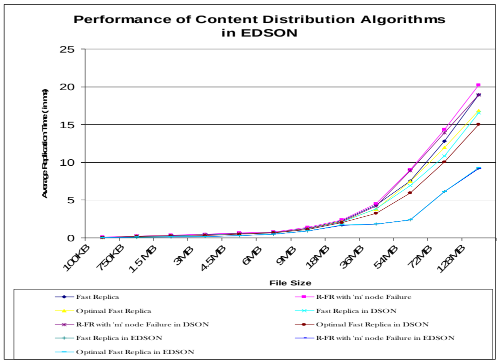

Fig. 4. Performance of different Content Distribution Algorithms in EDSON

"Fig. 4," shows the average replication time measured by different, individual recipient nodes for different file sizes of 100 KB, 750 KB, 1.5 MB, 3 MB, 4.5 MB, 6 MB, 7.5 MB, 9 MB, 36 MB, 54 MB, 72 MB,128 MB when the file is replicated in dominated replication set of surrogate servers. We measured the average replication time of different content distribution algorithms such as Optimal Fast Replica(O-FR), Resilient Fast Replica(R-FR) and Fast Replica(FR) across different file sizes in both traditional SON based CDN as well as DSON based CDN of surrogate servers.

We observed that average replication time of all the three content distribution algorithms such as Optimal Fast Replica (O-FR), Resilient Fast Replica(R-FR), and Fast Replica is reduced due to the use of equitable dominating set for reducing the number of surrogate servers in which replication of content carry out.

Role of Equitable Dominating Set and surrogate server utilization:

We evaluate the performance of CDN in terms of Net Utility (U_i) which can be given by the formula.

$$U_i = 2 / \Pi \ * \arctan (\alpha) \text{ ------------- } (4)$$

α – ratio between uploaded bytes to downloaded bytes. The resulting utility value ranges to [0..1].

The value U_i can be

$U_i = 1$ if the surrogate server uploads only content

$U_i = 0$ if the surrogate server downloads only content

$U_i = 0.5$ if upload and downloads are equal

We investigated the use of different overlay construction methodologies such as Semantic Overlay Network (SON), Dominating set based SON (DSON), and Equitable Dominating Set based SON (EDSON). It is observed that Net Utility U_i of individual surrogate servers is uniform in the Equitable Dominating Set based Semantic Overlay Network of surrogate servers. This is depicted in Fig.5.

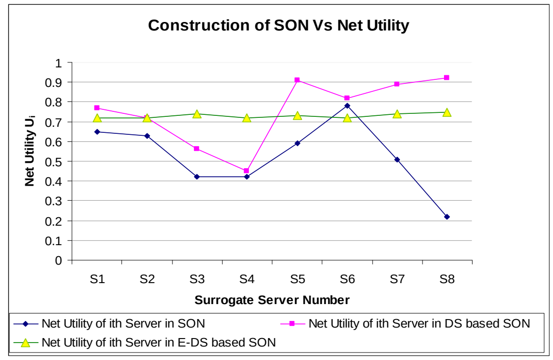

Fig. 5. Construction of SON Vs Net Utility

V. CONCLUSION AND FUTURE WORK

In this work, first we constructed equitable dominating set based semantic overlay network (EDSON) of surrogate servers for replicating the content from the origin server to a set of surrogate servers with the aim at placing the content nearer to the end user.

We have conducted simulation experiments using CDNsim and analyzed the performance of content distribution algorithms in terms of average content replication time and maximum content replication time for large files over SON. It is found that Optimal Fast Replica (O-FR) algorithm outperforms other content distribution algorithms.

We have performed both analytical study and empirical study for analyzing the performance of the content distribution algorithms.

We also investigated the effect of equitable dominating set in SON formation and how it was useful in reducing the redundancy. It is also observed that equitable dominating set based SON is useful in keeping the average replication time stable and much more predictable even though the content distribution algorithms differs We also investigated that how equitable dominating set based semantic overlay network is useful in maintaining the net utilization of individual surrogate servers much more stable and balance the load of individual surrogate servers.

ACKNOWLEDGMENT

The authors would like to thank the Project Coordinator and Project Directors of TIFAC CORE in Network Engineering, Arulmigu Kalasalingam College of Engineering for providing the infrastructure facility in Open Source Technology Laboratory and also thank Kalasalingam Anandam Ammal Charities for providing financial support for this work.

DOI: 01.IJNS.01.03.24

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DOI: 01.IJNS.01.03.24